FORMULAE FOR THE COMPUTATION OF THE LINE IMPEDANCE OF A SINGLE PHASE MULTIGROUNDED DISTRIBUTION CIRCUIT

The general expression for the line impedance, Z_L, in ohms per circuit mile of a multigrounded single phase line is as follows:

$$Z_L = Z_{11} - \frac{(Z_{1N})^2}{Z_{NN}} + \frac{1 - \frac{}{}}{S} Z_{NG}$$

where:

Z_{11} (the self impedance of the phase wire with ground return expressed in ohms per mile)

$= (R_e + R_1) + j\,(X_e + X_1)$.

$R_e = 0.00159\ f$, where f is the frequency in cycles per second.

R_1 = effective resistance of phase wire in ohms per mile. The value of R_1 may be obtained from the manufacturers' tables or electrical handbooks.

$X_e = 0.002328\ f \log_{10} 4{,}665{,}600\ \frac{\rho}{f}$, where ρ is the ground resistivity in meter-ohms. A value of 100 meter-ohms is generally assumed if it is not otherwise specified.

X_1 = inductive reactance of the phase wire in ohms per mile for one foot spacing. Values of X_1 are obtainable from manufacturers' tables or electrical handbooks.

Z_{NN} (the self impedance of the neutral wire with ground return expressed in ohms per mile)

$= (R_e + R_N) + j\,(X_e + X_N)$.

R_e and X_e same as in Z_{11} above;

R_N = effective resistance of neutral wire in ohms per mile. This value is available from manufacturers' data or electrical handbooks.

X_N = inductive reactance of the neutral wire expressed in ohms per mile for one foot spacing. Its value is available in manufacturers' data and in handbooks.

Z_{1N} (mutual impedance between phase and neutral wires with ground return expressed in ohms per mile)

$= R_e + j\ (X_e - X_D)$

R_e and X_e same as in Z_{11} above;

$X_D = \frac{2\ f}{1000}\ (.741 \log_{10} D)$

D is the spacing between phase and neutral wires in feet.

$X_D = 0.1682$, for $D = 4$ (standard REA single phase spacing) and $f = 60$ cycles/sec.

$Z_{NG} = \sqrt{R_g Z_{NN}}\ (1 - \mu^2)\ \tanh \gamma S.$

$R_g = \frac{R}{n}$

R = resistance per neutral wire ground in ohms.

n = number of grounds per mile.

$\mu = \frac{Z_{1N}}{Z_{NN}}$

$\gamma = \sqrt{\frac{Z_{NN}}{R_g}}$

S = length of circuit in miles from power source.

The term $(\frac{1}{3} Z_{NG})$ in the general expression of the line impedance, "Z_L", is a corrective factor which depends on the line characteristics and the length "S" of the line. This factor, for "S" equal to or greater than 10, becomes negligible. When there are no grounds on the neutral other than at the source, which is the actual case when "S" is very small, the impedance, "Z_L", becomes

the same as that of a metallic single phase circuit. Figure 1 shows graphically the variation of impedance per mile as the length "S" of the line is varied.

References:

1. Engineering Report 37 and 40 of the Joint Subcommittee on Development and Research of the Edison Electric Institute and Bell Telephone Laboratories.
2. Electric Transmission and Distribution Reference Book, Chapter 3.

IMPEDANCE OF SINGLE PHASE MULTIGROUNDED DISTRIBUTION LINES

Spacing: 4 Ft.

Ground Resistivity: 100 Meter-Ohms

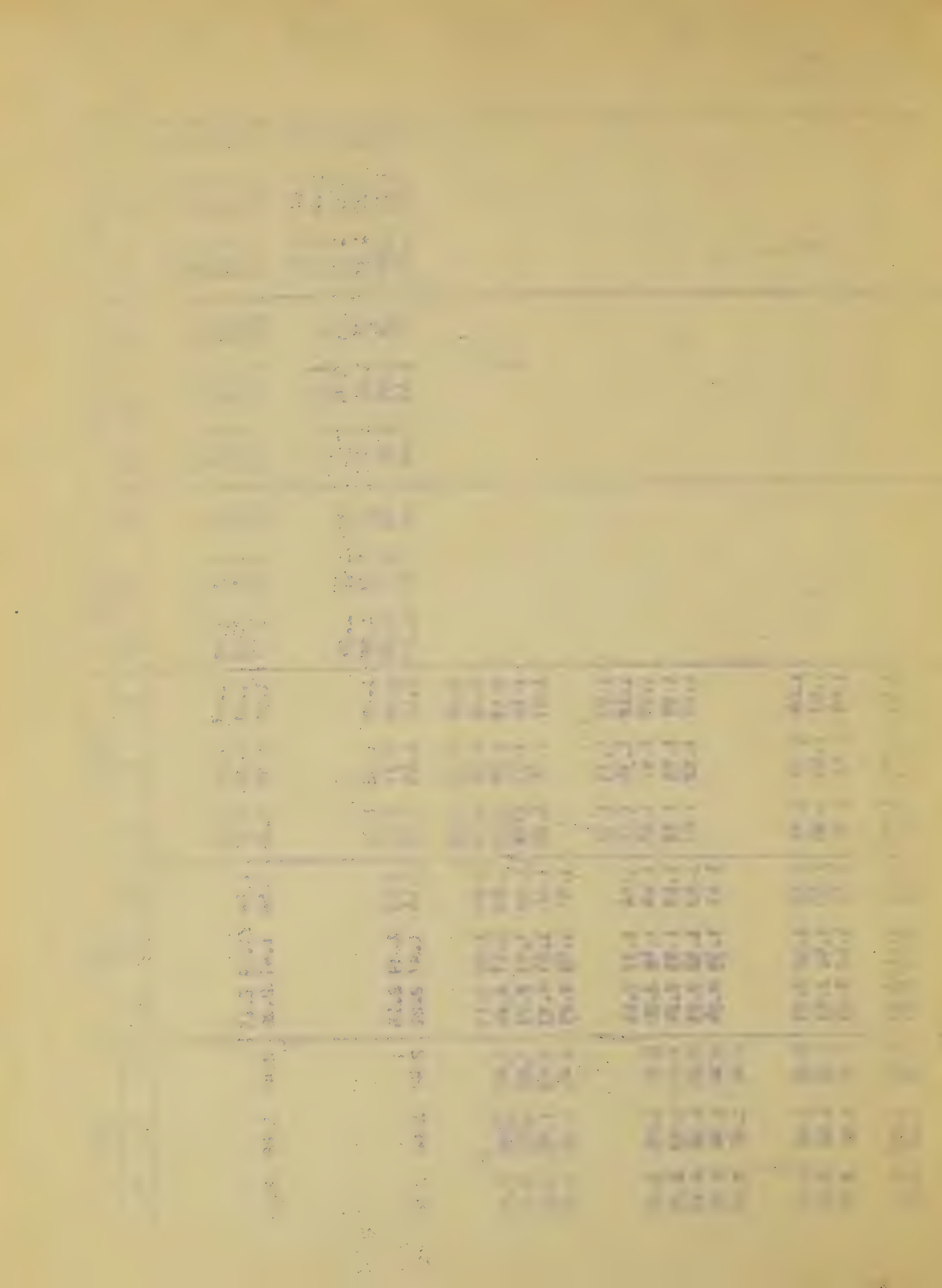
Length of Line: 10 Miles or More

Ambient Temperature: 25° C (77° F)

Frequency: 60 Cycle

Wire Denomination Neutral	Phase	COPPER														
		#2/0			#1/0			#2			#4			#6		
		R_L	X_L	Z_L	R_L	X_L	Z_L	R_L	X_L	Z_L	R_L	X_L	Z_L	R_L	X_L	Z_L
Copper	2/0	.57	1.12	1.26												
	1/0	.59	1.14	1.28	0.70	1.15	1.35									
	2	.64	1.18	1.34	0.75	1.20	1.41	1.07	1.22	1.62						
	4	.67	1.25	1.42	0.78	1.27	1.49	1.10	1.29	1.70	1.60	1.33	2.08			
	6	.67	1.33	1.48	0.79	1.35	1.56	1.10	1.37	1.76	1.61	1.41	2.14	2.41	1.44	2.80
A.C.S.R.	4/0	.56	1.14	1.27												
	3/0	.58	1.16	1.30	0.70	1.17	1.36									
	2/0	.60	1.17	1.32	0.72	1.19	1.39	1.03	1.21	1.59						
	1/0	.62	1.20	1.35	0.74	1.21	1.42	1.06	1.24	1.63						
	2	.66	1.26	1.42	0.78	1.27	1.49	1.10	1.30	1.70	1.60	1.34	2.09			
	4	.67	1.34	1.50	0.79	1.35	1.56	1.10	1.38	1.76	1.61	1.42	2.12	2.41	1.45	2.81
Copperweld	2A							1.07	1.23	1.62						
	4A							1.10	1.30	1.70	1.60	1.33	2.08			
	6A							1.11	1.37	1.77	1.61	1.41	2.13	2.41	1.44	2.81
	8A							1.08	1.44	1.80	1.59	1.48	2.16	2.39	1.51	2.83
	$9\frac{1}{2}$D							1.06	1.47	1.82	1.56	1.51	2.17	2.37	1.54	2.83
	3-12													2.34	1.56	2.83
Amerductor	2							1.05	1.24	1.63						
	4							1.11	1.27	1.69	1.61	1.31	2.08			
	6							1.10	1.37	1.76	1.60	1.41	2.14	2.41	1.44	2.81
	8							1.08	1.44	1.80	1.58	1.48	2.16	2.39	1.51	2.83
	8X							1.09	1.43	1.79	1.59	1.47	2.16	2.39	1.50	2.82
	9X										1.57	1.49	2.16	2.38	1.52	2.82
	10													2.36	1.55	2.82
Steel	4 (10A)							1.02	1.50	1.81	1.52	1.54	2.16	2.33	1.57	2.81
	6 (10A)							1.01	1.51	1.82	1.51	1.55	2.17	2.32	1.58	2.81
	8 (10A)							1.00	1.52	1.82	1.50	1.56	2.16	2.31	1.59	2.80
Steel	4 (50A)							1.00	1.52	1.82	1.50	1.55	2.16	2.31	1.58	2.80
	6 (50A)							0.99	1.52	1.81	1.49	1.56	2.16	2.25	1.59	2.76
	8 (50A)							-	-	-	-	-	-	-	-	-

Type Neutral	Phase	A. C. S. R.															
		#4/0			#3/0			#2/0			#1/0			#2			#4		
		R_L	X_L	Z_L	R_L	X_L	Z_L	R_L	X_L	Z_L	R_L	X_L	Z_L	R_L	X_L	Z_L	R_L	X_L	Z_L
	2/0	.58	1.17	1.31															
	1/0	.60	1.19	1.36	.71	1.20	1.47												
	2	.64	1.23	1.39	.76	1.27	1.48	.90	1.29	1.58	1.08	1.31	1.70						
	4	.67	1.30	1.47	.79	1.34	1.55	.93	1.36	1.65	1.11	1.38	1.77	1.64	1.39	2.15			
	6	.68	1.38	1.54	.79	1.42	1.63	.94	1.44	1.72	1.12	1.46	1.84	1.64	1.47	2.20	2.47	1.49	2.87
	4/0	.57	1.10	1.31															
	3/0	.60	1.18	1.32	.71	1.24	1.43												
	2/0	.62	1.20	1.35	.73	1.24	1.44	.87	1.28	1.54									
	1/0	.64	1.22	1.38	.76	1.27	1.47	.90	1.31	1.58	1.08	1.32	1.70						
	2	.68	1.29	1.46	.78	1.35	1.56	.94	1.37	1.65	1.10	1.37	1.77	1.63	1.39	2.15			
	4	.69	1.38	1.54	.79	1.43	1.64	.94	1.45	1.73	1.12	1.45	1.83	1.64	1.47	2.21	2.47	1.46	2.87
	2A										1.08	1.31	1.69						
	4A										1.11	1.38	1.76	1.64	1.39	2.15			
	6A										1.12	1.46	1.84	1.64	1.47	2.21	2.47	1.46	2.87
	8A										1.10	1.53	1.88	1.62	1.53	2.23	2.45	1.53	2.88
	9&10										1.07	1.56	1.89	1.60	1.57	2.23	2.43	1.56	2.90
	3-12													1.57	1.59	2.23	2.40	1.59	2.88
	2										1.07	1.33	1.71						
	4										1.12	1.36	1.76	1.64	1.37	2.14			
	6										1.12	1.47	1.85	1.64	1.46	2.20	2.47	1.46	2.87
	8										1.10	1.53	1.88	1.62	1.53	2.24	2.45	1.53	2.89
	8E										1.10	1.52	1.87	1.62	1.52	2.23	2.45	1.52	2.89
	9E													1.61	1.55	2.24	2.44	1.54	2.89
	10																2.41	1.57	2.86
	12																		
	4 (10A)										1.04	1.59	1.88	1.56	1.60	2.23	2.39	1.59	2.87
	6 (10A)										1.03	1.60	1.90	1.55	1.61	2.23	2.38	1.60	2.87
	8 (10A)										1.01	1.61	1.90	1.54	1.62	2.23	2.37	1.61	2.86
	4 (30A)										1.02	1.60	1.90	1.54	1.61	2.23	2.37	1.60	2.86
	6 (30A)										1.01	1.61	1.90	1.53	1.62	2.23	2.36	1.61	2.85
	8 (30A)																		



[illegible]	1.07	[illegible]	1.69															
[illegible]	1.10	1.33	1.72	1.61	[illegible]	2.10												
[illegible]	1.11	1.40	1.79	1.62	1.42	2.16	2.44	1.45	2.84									
[illegible]	1.10	[illegible]	1.83	1.60	1.49	2.19	2.42	1.52	2.86	[illegible]	[illegible]	4.03						
[illegible]	1.07	1.50	1.84	1.58	1.52	2.19	2.40	1.55	2.86	[illegible]	1.58	4.02	5.12	1.61	5.37			
[illegible]																7.52	[illegible]	[illegible]
[illegible]	1.05	1.27	1.66															
[illegible]	1.11	1.40	1.71	1.63	1.32	2.10												
[illegible]	1.11	[illegible]	1.78	1.62	1.42	2.16	2.43	1.45	2.83									
[illegible]	1.09	[illegible]	1.83	1.60	1.49	2.19	2.42	[illegible]	2.86	[illegible]	[illegible]	4.03						
[illegible]	1.09	1.44	1.82	1.60	1.42	2.18	2.43	1.51	2.86	[illegible]	1.53	4.03						
[illegible]				1.59	1.50	2.19	2.41	1.53	2.85	[illegible]	1.55	4.02	5.13	1.59	5.37			
[illegible]							2.39	1.56	2.85	[illegible]	1.56	4.02	5.11	1.65	5.37			
[illegible]										[illegible]	1.60	3.99	5.08	1.65	5.34			
[illegible]							[illegible]	1.58	2.84	[illegible]	1.60	4.00						
[illegible]							2.35	1.59	2.84	[illegible]	1.62	3.99						
[illegible]							2.34	1.60	2.83	[illegible]	[illegible]	3.98						
[illegible]							2.34	1.59	2.83	[illegible]	1.61	3.98						
[illegible]							2.37	1.60	2.83	[illegible]	[illegible]	3.97						

AMERDUCTOR

Wire Denomination Neutral / Phase	#2			#4			#6			#8			#8X			#9X		
	R_L	X_L	Z_L	R_L	X_L	Z_L	R_L	X_L	Z_L	R_L	X_L	Z_L	R_L	X_L	Z_L	R_L	X_L	Z_L
Amerductor 2	1.08	1.36	1.74															
4	1.13	1.39	1.79	1.66	1.39	2.17												
6	1.12	1.49	1.86	1.66	1.49	2.23	2.40	1.49	2.82									
8	1.11	1.56	1.91	1.64	1.56	2.27	2.38	1.56	2.84	3.70	1.56	4.02						
8X	1.11	1.54	1.91	1.64	1.54	2.25	2.38	1.54	2.84				3.43	1.54	3.77			
9X	1.10	1.56	1.91	1.63	1.56	2.26	2.37	1.56	2.84	3.69	1.56	4.01	3.42	1.56	3.77	4.27	1.66	4.59
10				1.61	1.60	2.27	2.34	1.60	2.84	3.67	1.60	4.00	3.40	1.60	3.76	4.25	1.70	4.58
12							2.32	1.62	2.83	3.64	1.62	3.98	3.37	1.62	3.74	4.22	1.72	4.56
Steel 4 (10A)	1.05	1.62	1.93	1.58	1.62	2.26	2.32	1.62	2.83	3.64	1.62	3.98	3.37	1.62	3.74	4.22	1.72	4.56
6 (10A)	1.04	1.63	1.93	1.57	1.63	2.26	2.31	1.63	2.82	3.63	1.63	3.98	3.36	1.63	3.74	4.21	1.73	4.55
8 (10A)	1.02	1.64	1.93	1.55	1.64	2.25	2.29	1.64	2.81	3.61	1.64	3.96	3.34	1.64	3.72	4.19	1.74	4.54
4 (50A)	1.03	1.63	1.93	1.56	1.63	2.25	2.30	1.63	2.82	3.61	1.63	3.96	3.35	1.63	3.72	4.20	1.73	4.54
6 (50A)	1.02	1.64	1.93	1.55	1.64	2.25	2.29	1.64	2.82	3.60	1.64	3.96	3.34	1.64	3.72	4.19	1.74	4.53

Wire Denomination Neutral / Phase	#10			#12		
	R_L	X_L	Z_L	R_L	X_L	Z_L
Steel ductor 10	5.77	1.70	6.00			
12	5.75	1.72	6.00	9.03	1.83	9.21
6 (10A)	5.74	1.73	6.00	9.02	1.84	9.21
8 (10A)	5.72	1.74	5.98	9.00	1.85	9.19
6 (50A)	5.72	1.74	5.98	9.00	1.85	9.19

Wire Denomination Neutral / Phase	STEEL														
	#4(10A)			#6(10A)			#8(10A)			#4(50A)			#6(50A)		
	R_L	X_L	Z_L	R_L	X_L	Z_L	R_L	X_L	Z_L	R_L	X_L	Z_L	R_L	X_L	Z_L
Steel 4(10A)	8.98	2.32	9.28												
Steel 6(10A)	8.97	2.33	9.27	11.67	2.35	11.90									
Steel 8(10A)	8.95	2.32	9.25	11.65	2.36	11.88	17.62	2.69	17.83						
Steel 4(50A)										15.02	4.26	15.62			
Steel 6(50A)										15.02	4.27	15.62	21.97	4.50	22.43